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STRATEGY FOR LONG-TERM SYSTEMS AND TECHNOLOGY ADVANCEMENT

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ABSTRACT

Many challenges have emerged within the past five years for both military customers, as they plan for and purchase aircraft, and for manufacturers, in producing these aircraft. Opportunities to develop new models of military rotorcraft have decreased with steady reductions in military budgets and the post cold-war environment. These budget reductions, coupled with quantum advances in computing technologies that have advanced ground-based and airborne processing power, have shifted the focus of military customers from new model development to increased aircraft performance via system upgrades and training.

The emphasis on meeting long-term operational needs with these upgraded systems and the training required to optimize their use has resulted in an imperative to change acquisition and implementation strategies for both the aircraft customer and the prime manufacturer. This paper focuses on the impact of these strategies on the rotorcraft industry, as follows:

Systems Engineering. The architecture of aircraft mission equipment packages must be carefully planned in order to provide the capability of rapid and cost-effective modifications and upgrades. Avionics architectures have long supported highly federated mission processing furnished by suppliers with highly proprietary technical solutions. These complex closed subsystems cannot be modified or upgraded without considerable expense, and soliciting equivalent functionality from other suppliers is cost-prohibitive. Re-engineering the supply chain process, scrutinizing avionics make-buy decisions, and concentrating systems engineering activities early in development programs can aid in satisfactorily and predictably meeting the long-term operational needs of both the military customer and the manufacturer.

Aircraft-level integration facilities. Ground-based systems integration solutions must supplant aircraft testing to the maximum practicable extent in order to accommodate rapid and economical test results without expending valuable aircraft time. Systems integration test stations that combine aircraft subsystems with subsystem emulations, math model simulation, and playback capability can provide a high degree of fidelity to on-ground testing, both prior to first flight and during the aircraft flight test program.

Training systems. Training for pilots, crews, and maintainers must move to improved on-ground training systems, such as full flight simulation trainers and non-motion cockpit trainers. In order to make the rapid changes required to keep trainers current with fielded aircraft, these trainers must also be developed utilizing a concept of optimizing open systems architectures and commercial off-the-shelf hardware and software. With fewer aircraft being purchased and more complex mission equipment in development, on-ground training solutions can provide aircraft personnel tools for becoming familiar and proficient with their tasks off the aircraft.

INTRODUCTION

Today's military customer wants

- An affordable airplane

- That meets performance requirements now,

- Has incremental performance upgrades planned that are affordable and schedule-efficient, and that also

- Has training for crew and maintainers that is concurrent and economical.

Some of the processes that can be utilized to maximize the ability to satisfy customer requirements are

1. Strong systems engineering focus at the inception of upgrade program planning that provides specific and quantifiable performance requirements such that the mission equipment package architecture and top-level requirements can be allocated to subsystems very early in the program.

2. Robust aircraft-level systems integration testing to eliminate common problems that can be resolved prior to first flight, to provide confidence that aircraft subsystems are interacting correctly and predictably prior to aircraft installation, and to support identification and resolution of problems after the aircraft has been fielded.

3. Training devices, including engineering simulation and flight training devices with and without motion. These trainers provide familiarization with the aircraft that can be performed prior to aircraft fielding, and reduce costs associated with utilization of the aircraft itself.

SYSTEMS ENGINEERING PROCESS

Every aircraft manufacturer has a long history in cockpit development programs and projects that have failed because their systems engineering was not sufficient to specify and allocate requirements that would meet the military customer's short- and long-term needs. For this systems engineering process to be successful requires communication between customer and aircraft manufacturer very early in the aircraft conception period, an orderly and disciplined formulation of mission equipment architecture and expected function, intelligent competitive procurement, and strong technical oversight following the procurement period from both the customer and the aircraft manufacturer.

It is difficult to assess the success of the systems engineering process, because the program must be concluded prior to being able to measure the results of the effort. This means that successful systems engineering requires an up-front investment in cost and schedule—which mandates trust and commitment by both the customer and aircraft manufacturer, with no guarantee of success. Bell Helicopter Textron Inc. has participated in many aircraft and systems upgrade programs—with varying levels of success.

At the completion of any aircraft development or upgrade activity, a systematic review should be undertaken to provide insight into the management of subsequent programs:

- How producible are the subsystems?

- How does the modified aircraft cockpit reduce crew and maintainer workload?

- How easily modified are the cockpit systems from this point forward?

- How capable are the subsystem suppliers in repeating previous success?

- How have the subsystem suppliers addressed technology obsolescence?

This review cannot take place until the mission equipment package has been deployed for a time period sufficient for early box failures and customer evaluation to have taken place, and by that time, most aircraft manufacturers are committed to other development programs.

As the benefits of systems engineering have become evident, Bell has developed some guidelines, with the aid of internal investments in process and product improvements, that, over the past three years, have yielded positive results in expertise and in potential repeatability of success.

Improvements have been made in the following three areas:

- Mission Equipment Package planning

- IR&D involvement for future benefits in systems engineering, in particular

  1. Process improvements

  2. Product development knowledge

- Supplier selection

Mission Equipment Package Planning
In the area of Mission Equipment Package planning, technical and management involvement with the customer to understand and clarify a near- and long-term vision for the aircraft upgrade has been highly successful. On the H–1 Upgrade program, Bell and NAVAIR set up complementary team structures within each of their organizations, called Integrated Product Teams, which conducted trade studies to determine the optimal mission equipment package to meet customer desires while fitting into their funding profile. This structure was assembled prior to any avionics supplier selection and allowed aircraft requirements to be logically allocated to subsystems along with targets for weight, cost, reliability, and maintainability.

Bell employs this methodology on other cockpit development programs for the military, as well as on commercial programs, where Bell considers the Federal Aviation Authority (FAA) to be the customer. Forming a working team, consisting of management and technical contributors, early in the program allows the mission equipment package architecture to be defined and decisions made such as federated versus distributed subsystems, make versus buy, and subsystem vendors, and culminates in a program-level Preliminary Design Review. This Preliminary Design Review signifies the time at which all requirements are understood by the airframe manufacturer and subsystem suppliers, and at which the customer understands the limitations of the manufacturer and supplier solutions. At this point, there should be confidence, if the systems engineering process has been employed

well, that the probability of successful implementation on the aircraft is high.

This process has worked well on the H–1 Upgrade Program, as well as the V–22 program and its variants, also deliverable to the U.S. Navy and Marines. On the H–1 Upgrade Program, robust systems engineering led to the selection of Litton as the major cockpit system supplier, with ancillary suppliers for other airborne systems. In addition, informed trade studies resulted in the Bell in-house development of the H–1 Flight Control System (FCS) and two types of interface processing units, called Wiring and Integration Remote Terminals (WIRT).

As a more detailed example of proficient systems engineering with long-term supportability, the H–1 Upgrade Program FCS is identical for both UH–1Y and AH–1Z aircraft, and needs only two card types to meet its functional specifications: a CPU card and an axis card. The current customer requirement for a three-axis system uses one CPU card and three identical axis cards, and a fourth (with accompanying power supply) can be added into the spare card slot if a fourth axis is funded by the customer in future. The design of these subsystems within Bell were leveraged from an on-going IR&D project, which is detailed in the following section.

IR&D involvement for future benefits in systems engineering

Bell, since 1995, has focused a portion of its internal research and development (IR&D) funding on improvements in systems engineering, specifically in areas of process improvement and in product development knowledge.

Process improvements. Two sets of activities have raised awareness and increased the knowledge base within Bell of our internal systems engineering processes, and have provided a framework for improving the aircraft mission equipment development process on future programs. These investments have yielded excellent results, as described below:

1. Independent capability assessments via the Carnegie Mellon Software Engineering Institute (SEI) Software Capability Maturity Model, both for technical oversight of suppliers and for in-house software development efforts. The entire Systems Integration organization at Bell was assessed in August 1996 at a high Level 1 (Initial), and reassessed in October 1997 at Level 2 (Repeatable), both times by an independent consulting agency. The Systems Integration organization, which includes all system design areas (avionics, armament, electronic warfare, flight controls, and electrical systems) and hardware, software, and test design capability for these systems, expects to achieve Level 3 (Managed) at their next

assessment scheduled for August 1999. This commitment to improve internal processes and to actively seek objective assessments of these processes has driven Bell to make their systems and software processes and the technical management of their avionics system suppliers consistent between projects and has provided guidelines for training the engineering staff.

2. Benchmarking activities were conducted in 1998 by a Design & Producibility Team, staffed with Engineering and Manufacturing personnel tasked with evaluating the development process in the industry, as it existed in key companies. This team conducted benchmarking throughout aerospace and related industries to identify "best in class" practices to be adopted at Bell for reducing schedule and cost in aircraft development and upgrade programs. This benchmarking activity has resulted in the formulation of a development template for measured and concurrent product development and upgrades which tie all responsible functional areas together to reduce traditional schedule and cost impacts. This template will be utilized to predict future program costs based upon historical data, and will increase the repeatability of success on subsequent programs.

Product development knowledge. The Advanced Systems and Technology Integration (ASTI) program was initiated in 1996, in part to provide insight into the use of a generic avionics architecture, and to provide a series of prototype hardware and software components that can be easily migrated into flightworthy components. The goals of this IR&D program were twofold: to keep in-house development capabilities current with technology, and to make Bell engineering "smart managers" in the area of technical supplier oversight for complex airborne systems.

There were three main areas of avionics hardware and software investigated: data acquisition systems, instrument display systems, and mission computers. Within each of these areas the following topics were examined: use of commercial off-the-shelf (COTS) hardware and software components, improved system and software development toolsets, and open system architectures. The efforts of the ASTI program have thus far resulted in the following accomplishments:

1. Dual use (for both military and commercial applications) data acquisition system hardware and software using COTS components.

2. Generic object-oriented display software components for design, evaluation, and real-time use in instrument display systems.

3. Increased awareness of the advantages of open system architectures.

Recent focus by the military on the reduction of development costs, the increased use of commercial off-the-shelf (COTS) parts and processes, the use of improved system and software processes, and the design of open system architectures, has resulted in changes in the subsystem development process. The COTS label encompasses more than using industry standard components; it also entails using industry standard systems, processes, and tools. Improved software processes and toolsets focus on increased software reuse, maintainability, and customer satisfaction, using open system architecture as the foundation for facilitating these initiatives.

Integrating COTS components into military designs requires determining how to modify a military design to use COTS components as well as how to modify the COTS components to work in a military design. Thus far, the use of COTS in the military has mostly been at the component level.[1] However, there is much more to be gained if industry standard systems, processes, and tools can be employed as well. An example of using industry standard tools might be the choice of C, C++, or Pascal compilers as opposed to past military standards such as Jovial or Ada. Another, potentially much more beneficial, approach to integrating COTS components is the concept of dual use. Dual use is the idea of developing systems that can be used in both commercial and military applications, thus attaining the benefits of coproduction. The benefits of using COTS components and systems in military products must be carefully weighed against compromising essential military specific requirements.

Open system architecture "is an architectural framework defined by Open Systems interface standards. Open Systems standard interfaces are clearly and completely defined interfaces that support interoperability, portability, and scalability."[2] The application of open system interface standards should be an integral part of the design process. Although using standard interfaces is the key to designing successful open system architectures, the selection of interface/firewall locations is also important. Selecting appropriate interface points in the system may allow subsystem and/or component reuse and/or upgrade with relative ease. The personal computer market is an extraordinary example of how open

system architectures can lead to efficient development of new products.

The Bell-funded ASTI program identified COTS, system/software process, and open system architecture topics and investigated their application to helicopter avionics components:

Data Acquisition Systems. The data acquisition unit (DAU) is a system that is connected to a variety of sensors and/or discretes for data collection. Each analog input is digitized through an analog-to-digital (A/D) converter, and then output for display or further processing using either a MIL-STD-1553 or ARINC 429 data bus. Likewise, each discrete input is either acted upon internally or passed on for display or further processing. The DAU can also provide several ancillary functions, such as storing system exceedences and stick shaking.

Several COTS options were investigated for use in the DAU. As is common, the main use of COTS was at the component level. All A/D, D/A, and processor cards were designed using COTS components, where possible. Various COTS input/output (I/O) boards were considered; however, none had the necessary channel capacity. Likewise, COTS processor cards were considered, but the unit cost for them was typically too high. The system's power supply was a selection from industry standard off-the-shelf components. In conjunction with DAU development, several industry standard off-the-shelf sensors (such as temperature bulbs, strain gauge pressure transducers, and chip detectors) were identified and implemented across multiple platforms.

During the process of DAU development, multiple industry standard processes and tools were used. Following is a sample listing of tools and their use:

* DOORS© – System requirements management and traceability.

* VIEWlogic® – Hardware schematic design.

* PADS© – Hardware trace routing.

* Green Hills© C – Software development environment.

* LDRA© – Software testing.

* PVCS© – Configuration management.

Many open architecture ideas were also investigated during development of the DAU. The chassis was designed for standard VME 6U form factor cards. A standard VME backplane was investigated; however, the VME standard did not provide the necessary undedicated I/O lines for sensor input. The VME 6U form factor card

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[1] Nordwall, Bruce D., "Buying Off-the-Shelf Challenges Military," *Aviation Week and Space Technology*, Vol. 146, (18):57–59, April 28, 1997.

[2] Roark, Chuck and Kiczuk, Bill, "Open Systems – a process for achieving affordability," *IEEE Aerospace and Electronics Systems Magazine*, Vol 12, February 2, 1997, pp 26–32.

size was chosen to allow inclusion of other existing VME 6U boards into the chassis if desired at a later point. The DAU was designed with two data output interface protocols: ARINC 429 and MIL-STD-1553. This has allowed dual use of the design for commercial and military projects.

The investigation into a data acquisition system has been a tremendous success. It has resulted in the DAU's inclusion in the current H–1 Upgrade Program, in the form of the Flight Control System (FCS), as well as two types of WIRT units, which serve as electronic interface units that process a variety of discrete and analog sensor inputs throughout the airplane. A variation of the DAU has also been used in the commercial Bell-Agusta Model 609 tilt-rotor program, as the Ice Protection Control System. The risk reduction benefit of the ASTI program has ensured qualified H–1 FCS and WIRT units prior to scheduled aircraft needs within cost targets. Fig. 1 shows the DAU system architecture as defined on the ASTI program, with generic serial bus interface capability for dual use.

Instrument Display Systems. The instrument display system (IDS) is a system that graphically displays digital and analog engine, transmission, electrical, outside air temperature, clock, and fuel system information, formerly displayed on multiple analog gauges. It also provides an interface for data entry related to various ship configuration and flight parameters, such as fuel tank configuration and weight distribution, as well as a maintenance mode interface to access stored engine parameters and engine exceedence information. Fig. 2 depicts the system architecture for the IDS.

The digital flat panel display also allows the use of multiple colors to indicate normal, caution, and danger ranges. Fig. 3 shows a sample IDS display in black and white. The IDS engineering evaluation unit created during the ASTI investigation was developed almost entirely from COTS components. DY4© VME-based CPU and graphics cards were used to generate the graphical objects, simulate the input signals, and simulate the MIL-STD-1553/ARINC 429 interface. Two Sharp© flat panel displays were used to display the sample IDS screens, and WindRiver©'s VxWorks® real-time operating system was used to isolate the developed software from the hardware. Several other COTS products, including a Radstone© CPU board, were also evaluated as alternatives to the above configuration as part of the ASTI program.

During IDS exploration and development, several industry standard processes and tools were evaluated. One of the main tools explored was Virtual Prototype©'s VAPS® product, which allows quick creation and demonstration of display screens.
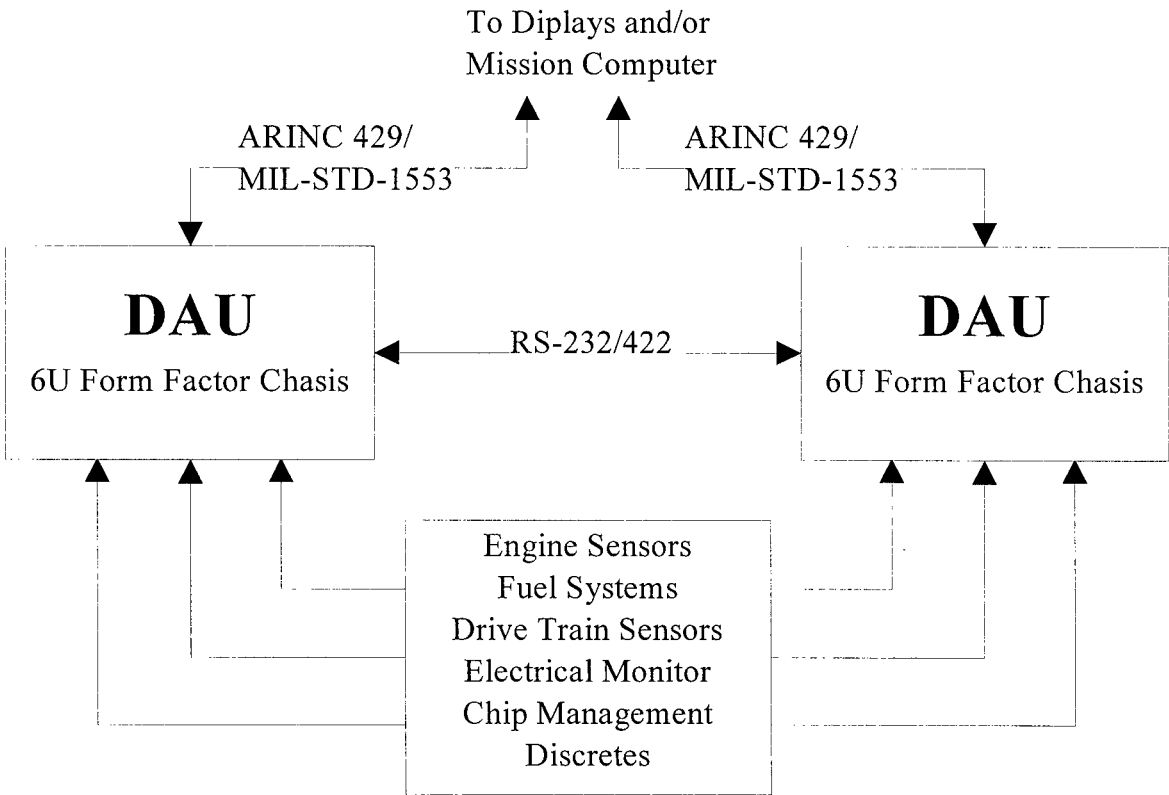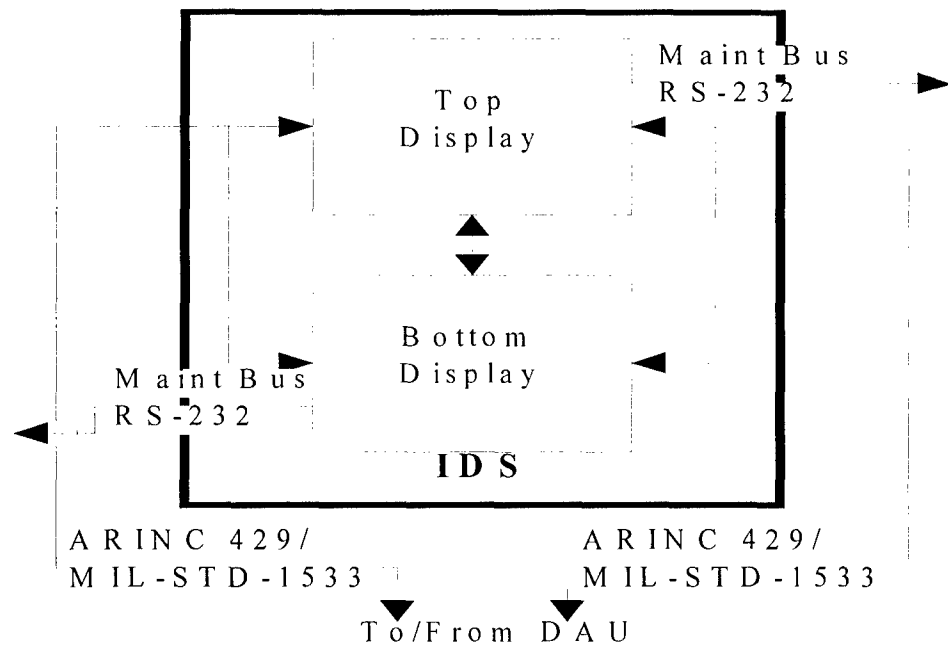

Fig. 1. DAU system architecture.

Top
Display

Maint Bus
RS-232

Bottom
Display

Maint Bus
RS-232

IDS

ARINC 429/
MIL-STD-1533

ARINC 429/
MIL-STD-1533

To/From DAU

Fig. 2. IDS system architecture.

MGT
0

MGT
0

Q_{TOTAL}
0

N_G
0

N_G
0

N_P
0   0

N_R
0

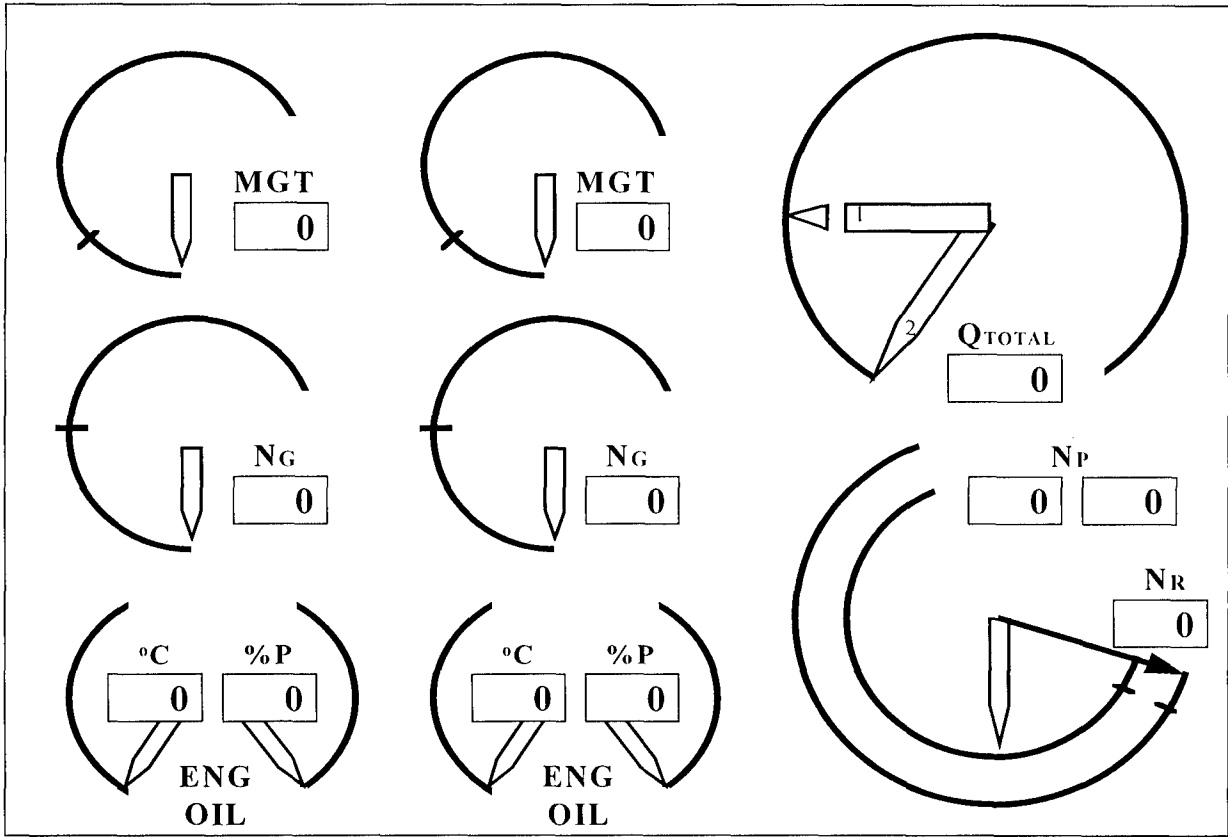°C   %P
0   0

°C   %P
0   0

**ENG
OIL**

**ENG
OIL**

Fig. 3. Sample IDS display.

VAPS® provides a graphical user interface (GUI) that permits point-and-click design and demonstration of potential IDS display formats. It also provides a tool to convert the display formats into C-code that can then be compiled and executed on many different target systems. One of the ASTI program's goals was to successfully port the generated C-code into the real-time hardware, and use it to generate and update the displays in real time. During this process, several problems related to porting the C-code to the DY4© platform were encountered. But with help from Virtual Prototypes© and DY4© support personnel, the problems were quickly overcome. However, the final determination was that the update rate of the VAPS®-generated code was too slow to be directly applied on the selected hardware platform, and that validation and certification of the generated code might be difficult.

Once the VAPS®-generated code was deemed unusable for real-time use on the selected hardware platform, a library of C++ objects was developed to allow easy generation of IDS display formats in real-time software. The Bell Avionics Prototyping and Real-time Software (BARS) library contains objects to display any of the following instrument types at any position, rotation, or size:

- Dial — Standard circular, or partially circular, instruments with user defined indicators.

- Text — Digital readouts.

- Ribbon — Vertical bar that indicates the current value by its height.

- Warning/Caution/Advisory — Matrix of cells that display system messages.

- Tape — Horizontal region that can be used to display current heading information.

- Ruler — Vertical or horizontal "ruler" with an indicator pointing to the current value.

- Attitude — Attitude indicator.

The same IDS displays were recreated using the BARS library, and the hardware was easily able to achieve the desired update rate. The BARS software was designed using a layered approach in order to ease the transition between hardware platforms. All BARS graphical commands are based on the industry standard graphical language called OpenGL®. Certain hardware vendors may supply an OpenGL library; those that don't would require modification of an existing library to allow interfacing into their unique vendor software.

Open architecture concepts were used at the system level, such that any COTS display that can be programmed with C++ (or C with some BARS modifications) and that provides an ARINC 429 interface is a viable option for use in this architecture. In fact, the process of rehosting the software into a new graphical hardware system was demonstrated using the Radstone© hardware. Another method used to keep the architecture open was the use of OpenGL in the layered software design previously described. OpenGL is increasingly supported by vendors, so the need for the user to create an OpenGL interface for each new display unit should diminish.

The results of the IDS exploration include a software library toolset that can easily be used to generate IDS displays and can easily be ported to new hardware platforms, a standard interface into display systems, and a list of potential vendors for such display systems.

Mission Computer. A generic definition of a "mission computer" is a system that coordinates and disseminates information. It is responsible for requesting information from data collection systems (such as the DAU), possibly altering the information in some manner, and then sending that information to other systems.

The COTS options explored on the ASTI program were very similar to those explored in the DAU and IDS efforts. An off-the-shelf VME chassis was selected due to industry-wide acceptance. There are numerous vendors that provide CPU and communication cards for the VME chassis. In order to isolate the software from the hardware, WindRiver©'s VxWorks® real-time operating system was used. The use of an operating system allowed the interchange of CPU and communication cards from different vendors.

Improved system and software processes learned on the ASTI program will provide additional benefits to mission computer development in the future. The use of defined processes, with reuse in mind, aided, and will continue to augment, the development of a suite of software modules that can be reused repeatedly with only minor modifications. There will always be unique portions of mission computers; however, if developed correctly using open architecture concepts, there will be a large quantity of reusable system software.

In the mission computer case, open architecture concepts tied in very closely with the use of COTS systems and components. By selecting an industry standard VME chassis, an open architecture was effectively created. Taking this a step further and requiring the use of a real-time operating system like VxWorks® made for an even more desirable environment. This environment easily supported each of the key components of open systems:

- Interoperability

- Portability

- Scalability

The investigation into mission computers and their architecture provided good insight into the benefits of COTS hardware and software, improved system and software processes, and open architecture ideas. This insight will significantly aid in new product development as well as subcontract management of current and future mission computer applications.

The efforts of the ASTI program resulted in the following list of accomplishments:

- Dual-use data acquisition system hardware and software using COTS components.

- BARS software components for design, evaluation, and real-time use in instrument display systems.

- An increased awareness of the advantages of open system architectures.

These lessons learned are already being applied to both military and commercial programs. ASTI not only provided this concrete list of accomplishments, it also provided an increased knowledge base that will improve in-house development and subcontract management now and into the future.

In short, commercial off-the-shelf parts and processes, improved system and software processes, and open architecture concepts can not only provide more elegant solutions, but solutions that are also more cost effective for military as well as commercial businesses.

Supplier Selection
Selection of vendors has long been a function of lowest cost with compromises made in technical, program management, and past performance areas. The mandate to select the "best value" supplier has forced the source selection group to scrutinize their previous process for competitive procurement, and to modify their definition and implementation of "best value". History has shown that cost has driven the procurement decision, while technical scores tended to cluster together, with small score differences even if there were large technical differences in the proposals. Recent selections have placed more emphasis upon technical and past performance scoring, and have normalized proposal scores so that technical and past performance scores have more weight in the final score, and therefore, the supplier selection. Two examples include the H–1 Upgrade Program selection of Litton for major cockpit subsystem supplier, and

the V–22 Full Flight Simulator selection of FlightSafety International as the supplier of simulator elements.

AIRCRAFT-LEVEL INTEGRATION FACILITIES

Another risk reduction activity that reduces the cost of mission equipment package development and provides confidence in the overall success of an aircraft upgrade program is an aircraft-level integration capability. Subsystem development, when tested within the supplier's environment, then must be commingled with all other components of the mission equipment package to be put through the rigors of aircraft-level testing. Typically, these subsystems have been tested via interface protocols with emulated signal and sensor inputs, but have not received actual communication from aircraft avionics. Aircraft-level systems integration, which includes systematic tests which may be run in batch form, are conducted on the aircraft integration bench, and any problems found are scrutinized to identify the subsystem at fault, the root cause, and any necessary workarounds or fixes.

Over the past fifteen years, Bell has evolved a high competence level in the design and fabrication of aircraft-level systems integration benches. This evolution began with the Model 400 bench to provide cockpit subsystem developers with the capability to test their units in the context of the aircraft, and includes breakout of all aircraft signals, emulation of these signals, setting and clearing aircraft faults that annunciate Warnings, Cautions, and Advisories. Tests can be repeated and optimized via automation. This evolutionary development of aircraft-level bench test capability migrated to all other Bell programs. For example, the OH–58D, CFUTTH, Bell-Boeing V–22, H–1 Upgrade Program, and Bell-Agusta 609 programs all have utilized aircraft-level integration benches, which are still in use for those programs with ongoing upgrades, modifications, or field problems.

For past integration benches, Bell utilized a set of cards developed in-house, called Universal Electronic Test Set (UETS) cards, which contained the capability to emulate sixteen signals of discrete, analog, monopole, thermocouple, and other types of signals and sensors. One chassis could house up to sixteen cards, and a set of three chassis could be accommodated in one rack. The Bell-Boeing V–22 Electronic Systems Test Lab (VESTL) utilizes two racks—or a total of over 2,000 signals in the mission equipment package. Software to control these signals, and to communicate with the aircraft systems, was coded in C++, also in-house.

COTS technology specifically geared for testing has advanced, and so for new aircraft-level benches, Bell is instituting a new set of hardware and software constructed to test all aircraft subsystems, both in the

hardware and software domain, and with the option of automating tests using new scripting features. These new components are

- VME National Instruments Mxi$^©$ interface – PCI to VME memory space converter.

- LabWindows CVI$^©$ – test software package.

- Windows NT$^©$ – operating system.

The Bell-developed integration benches are designed for portability, and can be broken down quickly for transport to any aircraft test site. The V–22 test bench has been disassembled and moved to the location of aircraft flight test in support of the Engineering Manufacturing Development program, and will be disassembled and moved again to support Low Rate Initial Production.

The fabrication of two aircraft-level integration bench facilities is currently in progress: one for the H–1

Upgrade Program, and one for the Bell–Agusta 609 program. The H–1 Integrated Test Station Floor Plan is depicted in Fig. 4, followed by a diagram of the bench architecture in Fig. 5.

The Bell–Agusta 609 Vehicle Management Systems Integration Lab (VMSIL), also in development, represents the most complex and robust integration bench ever built at Bell. It provides three separate system test capabilities: one for the avionics systems, one for the electrical systems, and one for the flight control system. These can be employed independently or simultaneously based upon test requirements. This bench also ties in the aircraft math model via a Silicon Graphics host machine, which allows complete testing of the flight control system. Test scripts have been written to provide batch test capability for rapid system testing for software and hardware releases to the VMSIL. In addition, the VMSIL has mission record and playback capability, which will make anomaly investigation easier. A block diagram of the Bell-Agusta 609 VMSIL is included as Fig. 6.
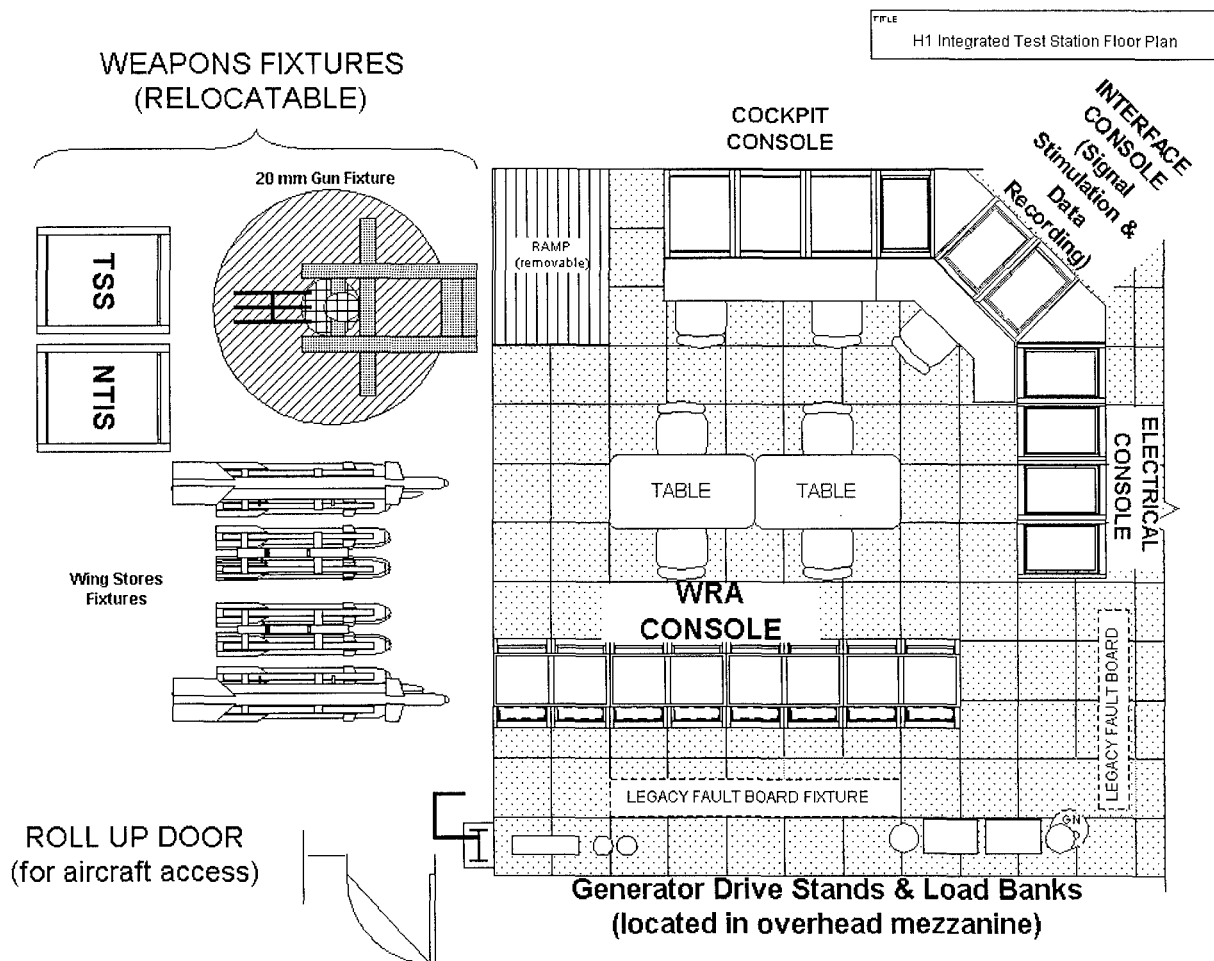

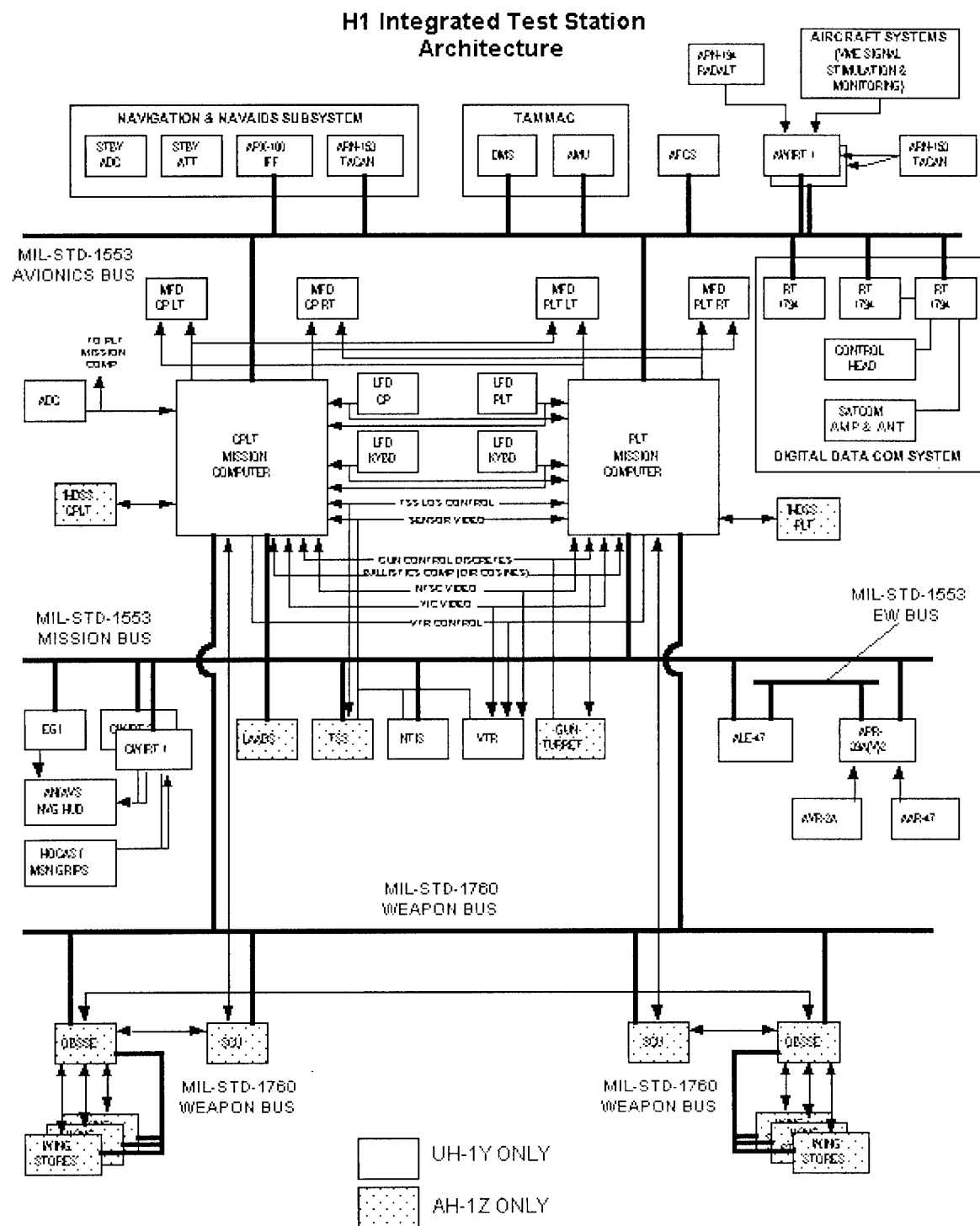Fig. 4. H–1 integrated test station floor plan.

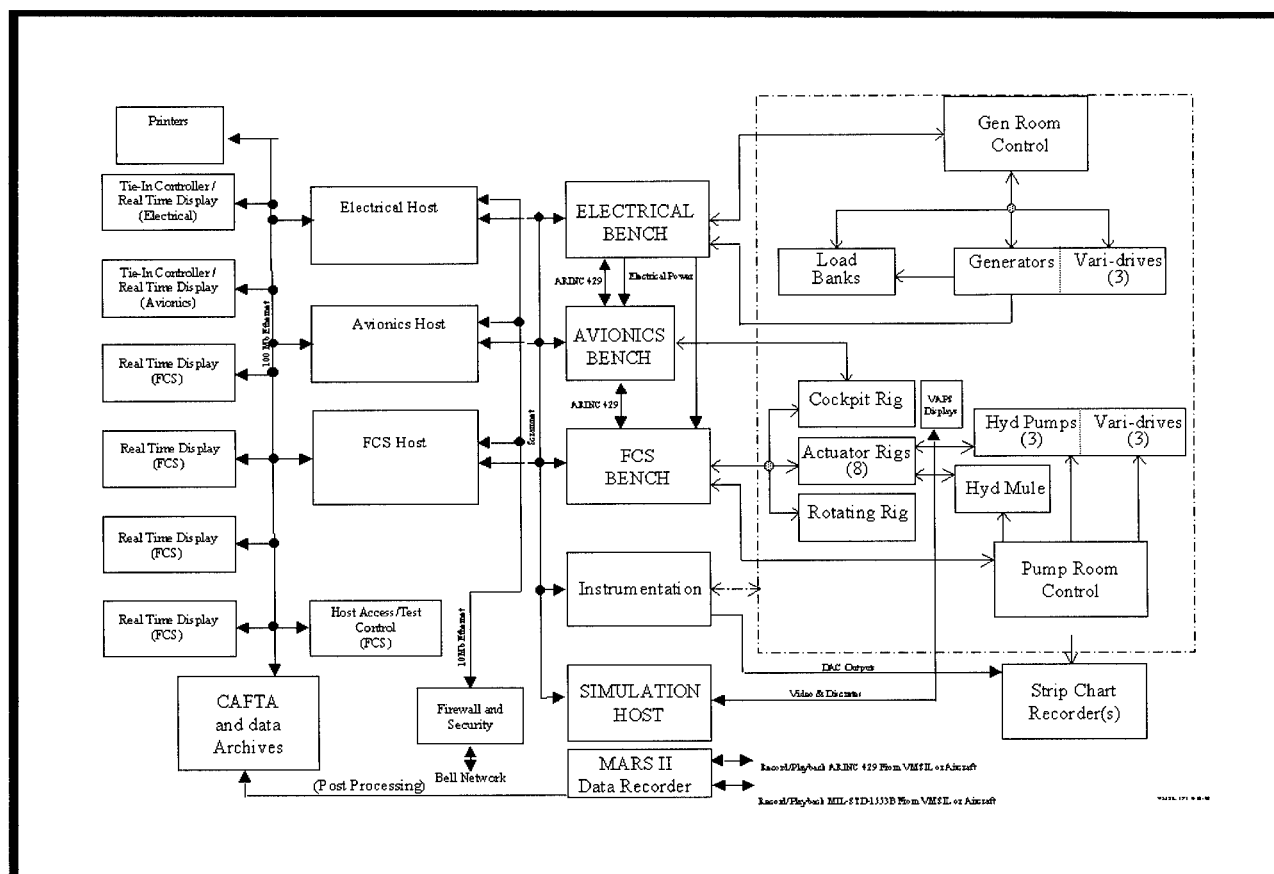Fig. 5. H–1 integrated test station bench architecture.

Fig. 6. Bell–Agusta VMSIL data system architecture.

TRAINING SYSTEMS

In order to minimize actual aircraft test time for crews and maintainers, it is important that economical, off-aircraft training is available and concurrent with the aircraft configuration.

Training needs can be met with simulation trainers, such as

- Engineering simulators.

- Flight simulators, with and without motion.

Engineering simulation is necessary for cockpit development, and provides interaction, familiarization, and hands-on experience for pilots, customers, and crew systems developers. Bell has an outstanding capability in the engineering simulation environment, where cockpit studies yielded optimal design and development of handling qualities, flight control laws, crew station ergonomics, and cockpit displays for the V–22 aircraft with variants, as well as for the H–1 Upgrade Program. The Bell engineering simulation is performed using

- ESIG 4530© – Visual system.

- SGI Origin 2000© – host computer.

Flight simulation is the next step for crew training, and Bell is in the forefront of state-of-the-art development on its V–22 Full Flight Simulator (FFS) program. Bell-Boeing selected FlightSafety International (FSI) as a design partner, and each partner has fulfilled design requirements for those areas in which they excel. The worksplit between Bell and FSI on the V–22 FFS was determined to maximize core capabilities both Bell and FSI: Bell is responsible for technical oversight, the aero performance model, math model shared memory, avionics subsystems (a combination of emulation and stimulation), data interchange, displays, and aural alerting, and FSI is responsible for providing the visual system, the cockpit and cab, and the test stations. The FFS is currently ahead of schedule and is underspent, and is expected to deliver up to five months earlier than its scheduled December 2000 delivery date, to New River, North Carolina, to begin 24-hour-a-day, 7-day-a-week training for the customer.

With aircraft concurrency as a requirement for the V–22 FFS, Bell-Boeing conducted trade studies in order to determine those avionics components most likely to be frequently modified, and utilized actual aircraft components for those items. For example, the mission

computers for the V–22 frequently undergo software modifications to add functionality or resolve problems, and so the actual aircraft units are used on the FFS, although when the mission computer development is considered mature, the mission computer function will be emulated. Other subsystems are also emulated in the aircraft software for the FFS. When software changes are made to the aircraft mission equipment, they can be easily and rapidly rolled into the V–22 FFS configuration, thus keeping the training concurrent with the aircraft.

In addition, with commonality between devices a customer desire, Flight Training Devices (FTD) also contracted by the customer for the V–22 program will be implemented with the same hardware and software as is the V–22 FFS, with the exception of the motion base. This approach minimizes non-recurring cost, and provides the customer an FTD before its scheduled due date. Updates, spares, and maintenance issues are addressed identically for both training device types. Fig. 7 shows the V–22 FFS integration architecture block diagram.

SUMMARY

Aircraft manufacturers face tremendous challenges in today's military environment where the customer's desire for cutting edge technology frequently outstrips available funding. The challenge for Bell and other aircraft manufacturers is to meet customer expectations while maintaining the delicate balance between cost, development time, and performance.

In order to meet this challenge, it is imperative that aircraft manufacturers improve their technological expertise and their development processes. This means a corporate commitment that may require internal investment.

Discipline in systems engineering can yield outstanding results in aircraft upgrade implementation, particularly in

- Definition of the mission equipment package.

- Delineation of the mission equipment package architecture.

- Allocation of requirements to the aircraft subsystems.

- Selection of suppliers that meet subsystem requirements with strong technical solutions and past history of program success.

- Collection of "lessons learned" at aircraft upgrade program completion.

- Investment in process improvements:

  1. In-house avionics development.
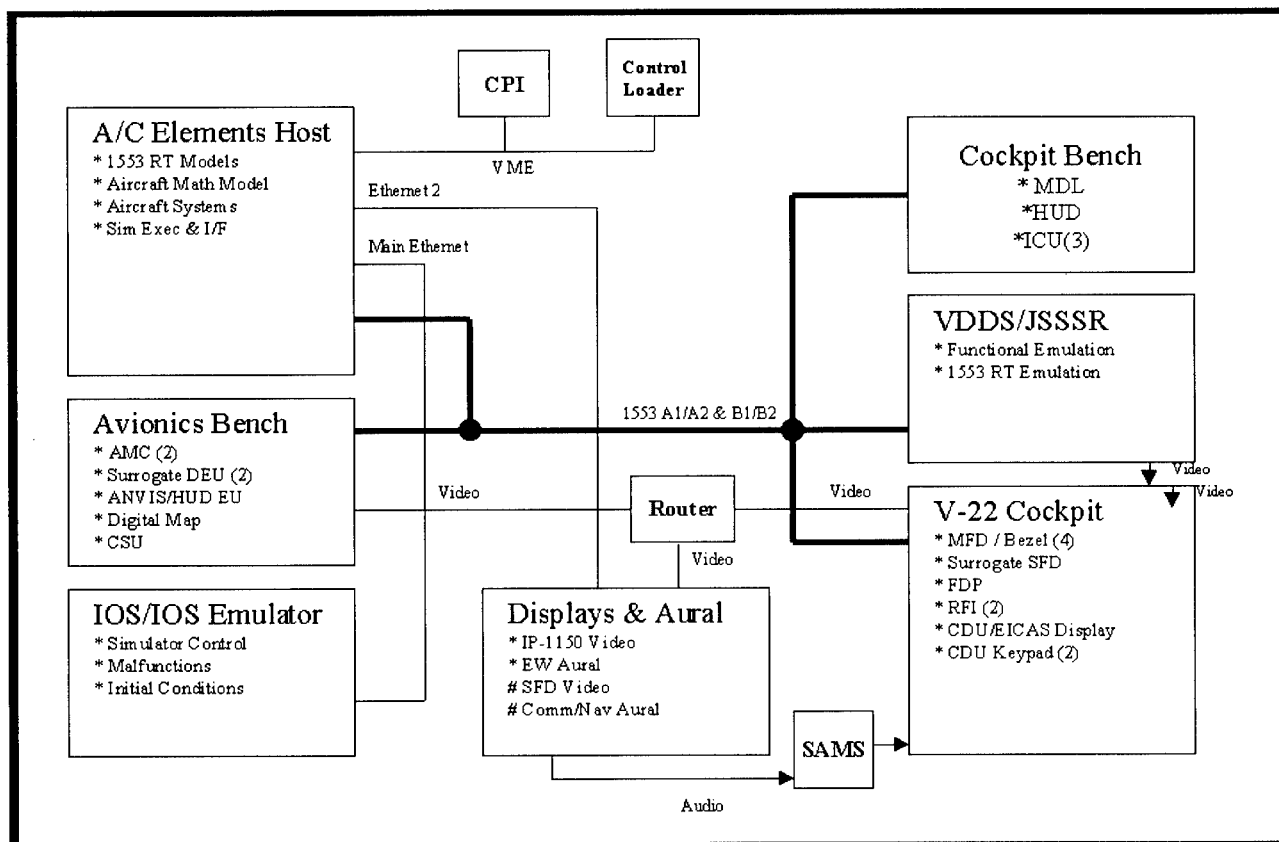 2. Smart buyers of avionics from outside suppliers.

Fig. 7. V–22 FFS integration architecture.

- Investment in product development knowledge.

- "Best value" supplier selection.

Following the detailed design and development period of an aircraft upgrade program, all subsystems must be assembled at one point prior to aircraft installation. While each subsystem may be operational in their respective test environments, their interaction in an aircraft-level integration environment is required in order to reduce on-aircraft testing and to resolve anomalies that could result in safety issues on the aircraft. Robust bench testing, in a location near the air vehicle, particularly during the development period, ensures that aircraft test time is optimized to expend flight time on only those functions that cannot be tested in a laboratory environment.

Lastly, off-aircraft training in a simulated environment reduces costly aircraft time for the development of cockpit displays and ergonomics and for aircrew flight training.

Bell Helicopter Textron has made significant investments in these processes and technologies, and has added "Systems Integration" to its list of six core competencies. For Bell, and for other aircraft manufacturers, the consideration and institutionalization of these elements into the engineering process adds a powerful tool for addressing the formidable task of introducing aircraft upgrades that are affordable and provide "best value" to the military customer.